Acoustic Clutter in Continental Shelf Environments

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LONG-TERM GOALS

Acoustic clutter is the primary problem encountered by active sonar systems operating in Continental Shelf environments. Clutter is defined as any returns from the environment that stand prominently above the diffuse and temporally decaying reverberation background and so can be confused with or camouflage returns from an intended target such as an underwater vehicle. Many environmental factors may contribute to acoustic clutter and adversely affect the performance of tactical Navy sonar by introducing false alarms in the system. In order to develop adaptive algorithms or technology to mitigate acoustic clutter, it is critical to identify, understand, and be able to accurately model the leading order physical mechanisms which cause clutter in existing sonar systems. The long-term goal of this program is to determine and understand the physical mechanisms that cause acoustic clutter in continental shelf environments and to use this knowledge to develop predictive tools to enhance the detection, localization and classification of underwater targets.

OBJECTIVES

The primary objectives of this program in FY2006 were to:

(1) Conduct a major offshore oceanographic experiment in the Gulf of Maine in the fall of 2006 to study acoustic clutter in the Georges Bank and Franklin Basin region.

(2) Conduct a joint experiment with the Mexican Navy in the Pacific Ocean to quantify hurricane destructive power with ocean acoustic measurements.

(3) Analyze Gulf of Main 2006, MAE 2003 and ARE 2001 data to identify the primary cause of *discrete and target-like* clutter observed in typical continental shelf environments such as the Gulf of Maine and New Jersey Strataform areas.

(4) Characterize the temporal and spatial properties of biological clutter as well as correlation to oceanographic or geophysical properties of the environment. This includes examination of clutter features over the full diurnal cycle, including both day and night observations.

(5) Determine the physical scattering mechanisms causing biological clutter and their variation with fish species, depth, size and population density.

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14. ABSTRACT

Acoustic clutter is the primary problem encountered by active sonar systems operating in Continental Shelf environments. Clutter is defined as any returns from the environment that stand prominently above the diffuse and temporally decaying reverberation background and so can be confused with or camouflage returns from an intended target such as an underwater vehicle. Many environmental factors may contribute to acoustic clutter and adversely affect the performance of tactical Navy sonar by introducing false alarms in the system. In order to develop adaptive algorithms or technology to mitigate acoustic clutter, it is critical to identify, understand, and be able to accurately model the leading order physical mechanisms which cause clutter in existing sonar systems. The long-term goal of this program is to determine and understand the physical mechanisms that cause acoustic clutter in continental shelf environments and to use this knowledge to develop predictive tools to enhance the detection, localization and classification of underwater targets.

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(6) Develop and use a new, rapid, rigorous and unified range-dependent reverberation and waveguide target scattering model based on the parabolic equation, a Fleet standard, to quantitatively determine the fundamental physical mechanisms responsible for clutter in active sonar operation in Continental Shelf environments and to provide predictive tools to mitigate or tactically exploit clutter.

(7) Apply a newly developed theory by the PI and his group to explain the experimentally observed fluctuations in clutter, reverberation and calibrated target returns in shallow water. This includes application of the only approach in existence for 3-D calculations of the mean forward propagated field and covariance in a random waveguide.

APPROACH

The approach is to combine the analysis of experimental data with full-field waveguide modeling of forward propagation, clutter, acoustic reverberation, and target scattering. Under the Acoustic Clutter Program the Acoustic Clutter Reconnaissance Experiment (ARE) 2001 was primarily aimed at just establishing the presence and persistence of acoustic clutter off the New Jersey continental shelf. The Main Acoustics Experiment (MAE) 2003 was designed to be very controlled, so that the actual mechanisms for the clutter could be established. It also had precise calibration so that theories and models could be accurately tested and validated. Full-field 3-D stochastic waveguide propagation and scattering models, simulations and statistical studies helped direct experiment design and support the analysis and interpretation of experiment results. The Gulf of Maine 2006 experiment was used to more carefully study simultaneously the local scattering characteristics as well as long range returns from both small schools and large shoals that lead to clutter in Navy sonar systems. This was done by use of both long-range Navy sonars in the low to mid frequency range as well as local conventional fish finding sonar and trawl vessels over an extended period of 3 weeks during both daytime and night time to examine the full diurnal variations of clutter.

In our hurricane work, the approach is to deploy underwater acoustics sensors in the location on earth most frequented by hurricanes, collect data for a period of roughly one year and correlate that data with local wind speed measurements. This will then be compared against data collected at another site, in the Mid Atlantic, and theoretical predictions published by the PI.

WORK COMPLETED/RESULTS

Bioclutter and Remote Sensing of Fish Populations: We have developed an underwater remote sensing technology for instantaneously detecting, locating and imaging fish populations over thousands of square kilometers in continental-shelf environments [Makris et al, Science 311, 660-663 (Feb. 3, 2006)]. Our new approach surveys at an areal rate roughly one million times greater than that of conventional fish finding methods. It does so by utilizing the ocean as an acoustic waveguide for efficient long-range propagation. With the technique, which we call Ocean Acoustic Waveguide Remote Sensing (OAWRS), we can continuously monitor fish population dynamics, behavior and abundance with minute to minute updates, producing records *unaliased* in space and time (essentially wide-area movies) that are valuable in the study of ocean ecology, conservation of ocean life, and preservation of marine fisheries.

With the "first look" of OAWRS in an experiment of the ONR Geoclutter Program in 2003, we were able to make a number of fundamental scientific discoveries about the (i) instantaneous horizontal structural characteristics, (ii) temporal evolution and (iii) propagation of information in very large fish shoals. These include the findings that: the instantaneous spatial distribution of fish over wide areas follows a fractal or power law process, so that structural similarity exits at all scales from meters to tens of kilometers (previously evidence for structural similarity existed only for small scales, tens of meters or less); large shoals are far more horizontally contiguous in 2-D than was previously believed based on 1-D line transect methods which inaccurately portray them as disjoint clusters; the temporal autocorrelation scale of population change within a very large shoal is extremely short, on the order of minutes, which is why fish shoals can suddenly disappear from conventional survey vessels; temporal fluctuations in shoal population also follow a power-law process, making them far more predictable; and fish density waves regularly propagate information over kilometer scales, orders of magnitude larger than previously observed, at speeds an order of magnitude faster than fish can swim, which apparently help large shoals remain cohesive. These observations were made from distances typically greater than 10 km from the shoals with sound at least three orders of magnitude less intense than conventional fish finding sonar.

We applied OAWRS again in Sept-Oct 2006 in conjunction with the National Marine Fisheries (NMF) Annual Herring Survey of Georges Bank and the Gulf of Maine in a multinational, multi-institutional oceanographic experiment sponsored by ONR, NOPP and the Sloan Foundation. With a single OAWRS transmission covering a 150-km diameter area, we were able to image a region in 75 seconds that would take the conventional NMF survey roughly one week to sparsely survey with several line transects. We found the NMF surveys could not accurately determine shoal morphologies or populations from their sparse line transects. We observed a startling new patterns of diurnal behavior, and many other discoveries about the migrations of spawning herring, their population, and the frequency dependence of scattering. We obtained direct trawl samples confirming fish species.

The Gulf of Maine 2006 experiment was a great success in demonstrating that discrete clutter events are consistently the major clutter problem in a region with significant bathymetric relief and variable oceanography. It was also a great success in determining that even in environments where fish populations are very deep with significant swim bladder compaction, and localized in very small schools, they still are the dominant source of acoustic clutter at long range. We showed that the many behavioral characteristics of the fish populations, including many unexpected diurnal idiosyncrasies, can be used to distinguish clutter from intended targets if sufficient time is allowed for monitoring. We demonstrated that many frequency characteristics of the long-range clutter returns can be also used to help classify the bioclutter and distinguish it from intended targets.

We have demonstrated that fish schools are dominant cause of acoustic clutter in typical continental shelf environment using data from Acoustic Clutter Experiment 2001, 2003 and the Gulf of Maine experiment of 2006. We showed in the Gulf of Maine as well as in the New Jersey Continental shelf that clutter features move with similar speed as underwater targets such as submarines and their spatial coherence scale is similar to many underwater targets, so that they can be easily confused with and misidentified as submarines.

Acoustic Propagation (Multiple Forward Scattering) Through a Fluctuating or Randomly Inhomogeneous Ocean: Sound waves in the ocean, like light in the atmosphere, twinkle as they pass through a turbulent or changing medium. We derived perhaps the only analytic solution available for acoustic field propagating through an ocean with random 3-D inhomogeneities [Ratilal and N.C. Makris, J. Acoust. Soc. Am. 118, 3560-3574 (2005)] in terms of waveguide modes. Although the derivation was lengthy, the final expressions are extremely compact, intuitively appealing and generally applicable to any kind of inhomogeneity in the ocean. This model makes it possible to quickly and intuitively determine when an acoustic field will remain coherent, or deterministic, when and how it will fluctuate incoherently, and how much attenuation to expect from scattering. While scintillation is sometimes a problem for remote sensing, it can also be advantageous since it smooths over complicated interference patterns that characterize propagation through a deterministic ocean, making it actually easier to remotely image distant objects.

We have extended our analytical model to determine the temporal coherence of sound after propagation through a slowly time-varying random medium. This model has been used to explain the roughly 10-minute time scale of acoustic field fluctuations observed at mega meter ranges in the North Pacific during Acoustic Thermometry of Ocean Climate (ATOC) experiments. It is shown that the time scale of acoustic field fluctuations is non-linearly related to the much longer 3-hour coherence time scale of deep ocean internal waves through a process of multiple forward scattering. We have showed that internal waves can lead to power loss in long range, low frequency propagation in the deep ocean.

Quantifying Hurricane Destructive Power with Undersea Sound: To obtain more data relating undersea sound and wind power in hurricanes, Professor Makris initiated and is currently leading a joint scientific collaboration with Mexico’s Navy (Secretaria De Marina). Professor Makris worked for several years with various ONR Latin America Station Chiefs and Program Managers and the US Embassy in Mexico City, to establish relationships with Mexico and obtain support from the Admiral commanding the Directorate of Oceanography, Hydrology and Meteorology. In June 2007, with generous collaboration from Mexico, which supplied one of its best oceanographic research vessels for two weeks, Prof. Makris led a scientific expedition with the Commander of Mexico’s Instituto Oceanographico Pacifico, and officers from Secretaria De Marina, to Mexico’s remote Pacific Isla Socorro, restricted to all but Navy personnel and special guests. Socorro experiences more hurricanes than anywhere else on earth. Two acoustic sensors were deployed within kilometers of shore near Secretaria De Marina’s meteorological station. Besides hurricane data, we also expect to collect a novel and rich set of bio-acoustic data, since Isla Socorro is surrounded by a famous marine sanctuary inhabited by many vocalizing creatures such as humpback whales.

IMPACT/APPLICATIONS

- We have designed and conducted a major international oceanographic experiment to study acoustic clutter in the Gulf of Maine in the fall of 2006. We found that as in the New Jesrey Strataform area, the primary cause of acoustic clutter is densely populated fish schools. We have measured the depth, frequency, spatial and temporal characteristics of this clutter to help mitigate it in Navy sonar systems.

- We have developed a partnership with the Mexican Navy to conduct scientific experiments in their waters to study ocean acoustic hurricane quantification. We have deployed sensors off the Mexican Isla Socorro, which experiences more hurricanes than anywhere else on earth. When retrieved in 2008, these will be used to test the ability to accurately quantify hurricane destructive power with acoustics.

TRANSITIONS

Transition of the Acoustic Clutter Program is already significant as documented by the great amount of Naval Research now focusing on clutter issues in active sonar which was spearheaded and guided by this Acoustic Clutter Program.

RELATED PROJECTS

Other organizations participating in the Geoclutter Program are Northeastern University, National Marine Fisheries Service, Institute of Marine Research Norway, NRL, ARL-PSU ...

PUBLICATIONS

P. Ratilal et al and N.C. Makris, “Long range remote imaging of the continental shelf environment: The Acoustic Clutter Reconnaissance Experiment 2001 Experiment,” J. Acoust. Soc. Am. 117, 1977-1998 (2005).

T.R. Chen, P. Ratilal and N.C. Makris, “Mean and variance of the forward field propagated through three-dimensional random internal waves in a continental-shelf waveguide,” J. Acoust. Soc. Am. 118, 3532-3559 (2005).

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S. Lee and N.C. Makris, “The array invariant,” J. Acoust. Soc. Am. 119, 336-351 (2006).

J. D. Wilson and N.C. Makris, “Ocean Acoustic Hurricane Classification,” J. Acoust. Soc. Am. 119, 168-181 (2006).

N.C. Makris, P. Ratilal, D. Symonds, S. Jagannathan, S. Lee, R. Nero, “Fish population and behavior revealed by instantaneous continental-shelf-scale imaging,” Science 311, 660-663 (Feb. 3, 2006). See extensive online supporting material and movies at Science website via free link on http://acoustics.mit.edu/faculty/makris/makris.html (Also featured in Nature Feb 9, 2006 “Research Highlights,” Physics Today “Search and Discover,” April, 2006, and elsewhere.)